Interaction Region / Magnetic Elements

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(with thanks to everyone who did real work and 'donated' items for my slides)

C0 Interaction Region

- C0 IR Optics requires new quadrupole and corrector magnets installed in the Tevatron
- Existing Tevatron layout and infrastructure impose boundary conditions
  - Beam height
  - Slot lengths
  - Operating temperature and allowable cryogenic loads
- Project startup and duration limit technical options
  - Extensive R&D prohibited by schedule
  - Limited modifications of existing designs
  - Use of existing production tooling and infrastructure
- Cost and schedule information based on current experience, more detailed information in process

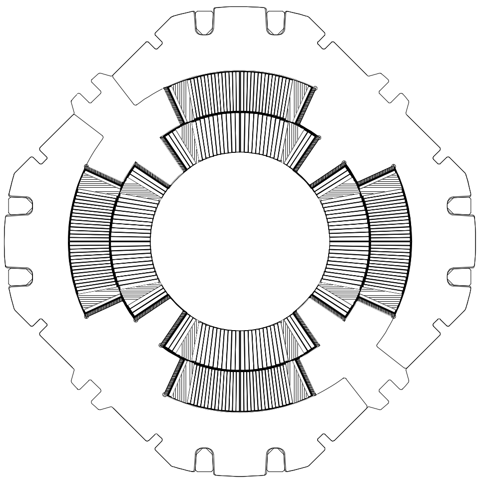
Q1 - Q5 Quadrupoles

- C0 IR design uses LHC Quadrupole as basis
  - Operate at 4.5K at C0 as opposed to 1.9K in LHC
  - 170T/m operation at C0 as compared to 214T/m
  - Lengths shorter than LHC
  - Collared coil provides all mechanical support—quench performance understood
  - Coil bore 70mm, beam tube ID 63mm
  - C0 Ramp Rate higher than LHC—155A/sec compared with 10A/sec

C0 IR Quadrupole Requirements

Magnet	Nominal Gradient	Magnetic Length	Magnetic Center	Mechanical Slot Length
	(T/m)	(m)	(m from IP)	(m)
Q1	169.2	2.41	14.263	3.520
Q2	165.4	4.43	18.749	5.476
Q3	169.2	2.41	24.661	3.520
Q4	170.0	2.01	65.115	2.974
Q5	170.0	1.37	86.911	2.441

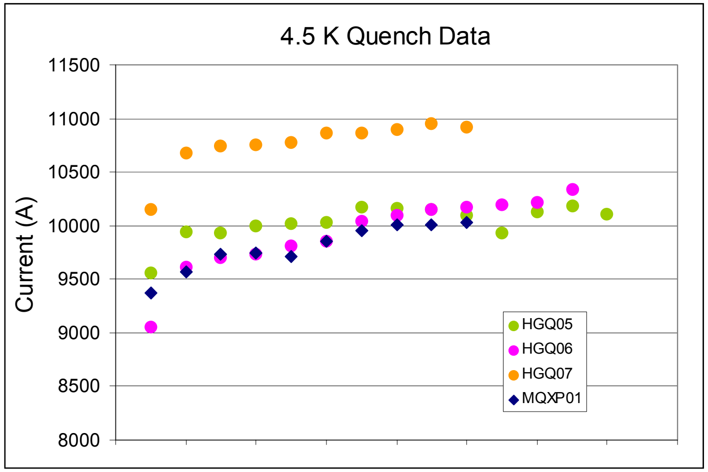
(4.5K Operating Temperature)



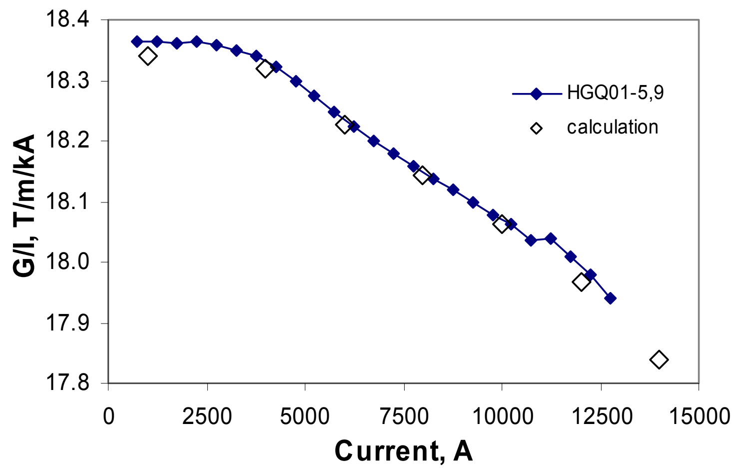
LHC Quadrupole Collared Coil Cross Section

Q1-Q5 Quadrupoles

- Quench limits are understood and experimentally proven through LHC program
- Harmonics agree well with expectation, modestly better than B0/D0 LBQs
- Transfer function agreement with calculation good



Quench Performance at 4.5K—170T/m = 9560A



Measured and Calculated Transfer Function Comparison

Average and standard deviations of the measured body harmonics at 11.9kA for the first 6 production LHC quadrupoles

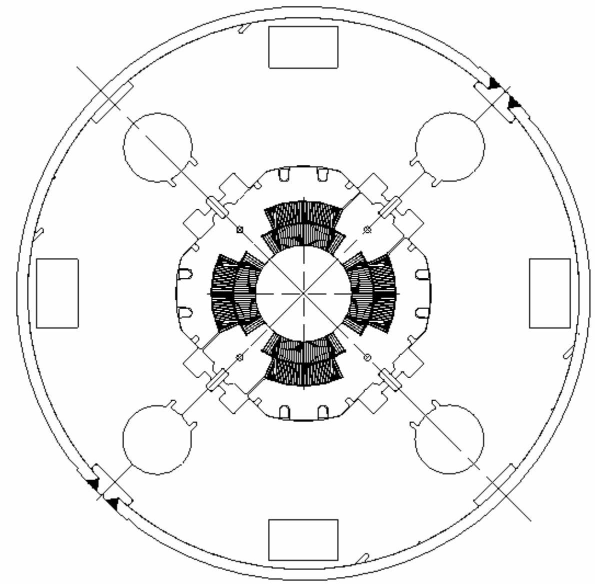
Harmonic Coefficient	Mean	RMS
b_3	0.31	0.47
a_3	-0.57	0.65
b_4	0.02	0.48
a_4	0.30	0.39
b_5	-0.03	0.13
a_5	-0.38	0.18
b_6	-0.02	0.45
a_6	-0.04	0.11
b_7	-0.01	0.03
a_7	0.01	0.03
b_8	0.00	0.02
a_8	0.01	0.03
b_9	0.03	0.01
a_9	-0.02	0.03
b_{10}	0.00	0.02
a_{10}	-0.03	0.02

Q1-Q5 Quadrupoles

- Optimizations / Areas for Further Study
  - Operation at higher ramp rate—degrades quench performance
    - Splice cooling?
    - Eddy current effects?
    - Fallback to roll off ramp rate at higher currents
    - Further LHC data mining and tests to be done
  - Reduction in yoke OD, and cryostat OD to fit in Tevatron
    - Complete electromagnetic calculations w/ final yoke
    - Modification of Quadrant Splice Design
    - Change in expansion loop design
  - Finalizing magnetic / mechanical lengths
  - Finalizing cryostat interfaces

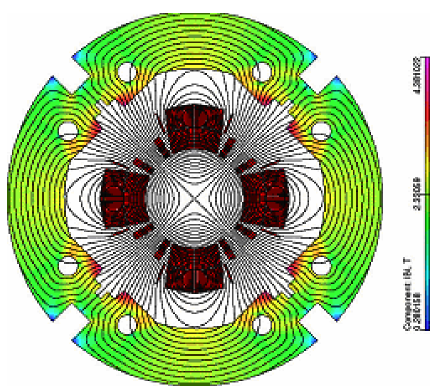
Q1-Q5 Quadrupoles

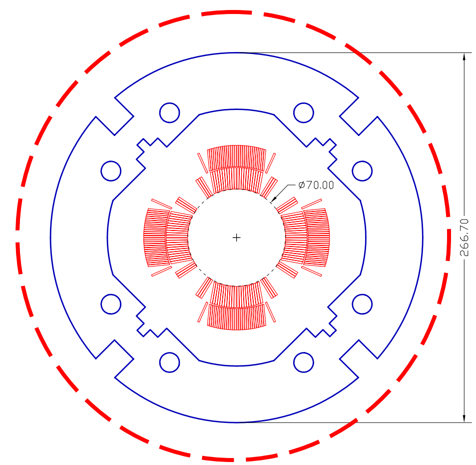
- Yoke Redesign
  - Harmonics known for LHC
  - Calculations complete for preliminary (smaller diameter) C0 design
  - Larger C0 diameter driven by end support and clearance for bus work
  - Cryogenic passages, bus slots to be confirmed



LHC Quad Magnet Cross Section

Preliminary C0 Yoke Cross Section used for calculations; the red circle is the current expected OD





Q1-Q5 Quadrupoles

- Mechanical / Magnetic Length Optimization
  - On order 1m allocated for 'mechanical stuff'
  - Coil ends, splice blocks, expansion loops, piping interfaces, bellows…
- Within allocation to date, discussions w/ AP on returning some turf

Magnet	Nominal Gradient (T/m)	Magnetic Length (m)	Magnetic Center (m from IP)	Mechanical Slot Length (m)
Q1	169.2	2.41	14.263	3.520
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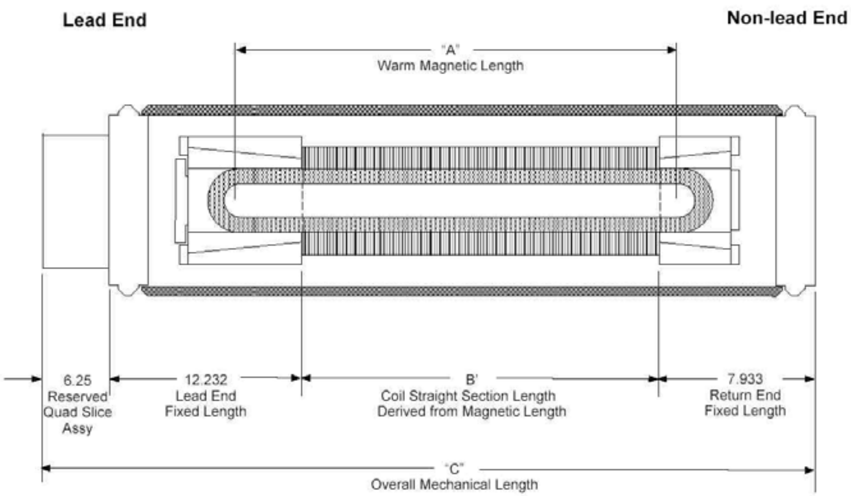
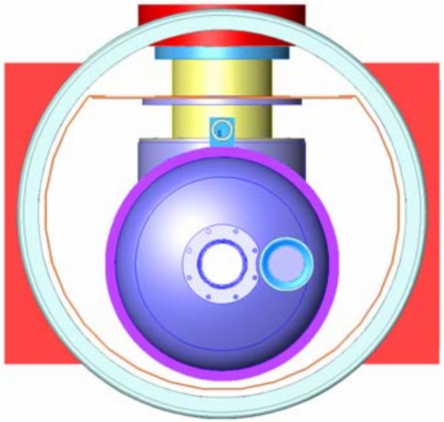
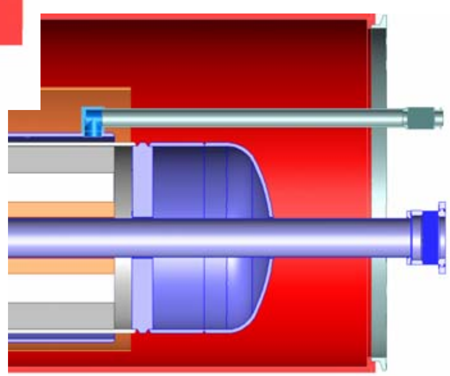
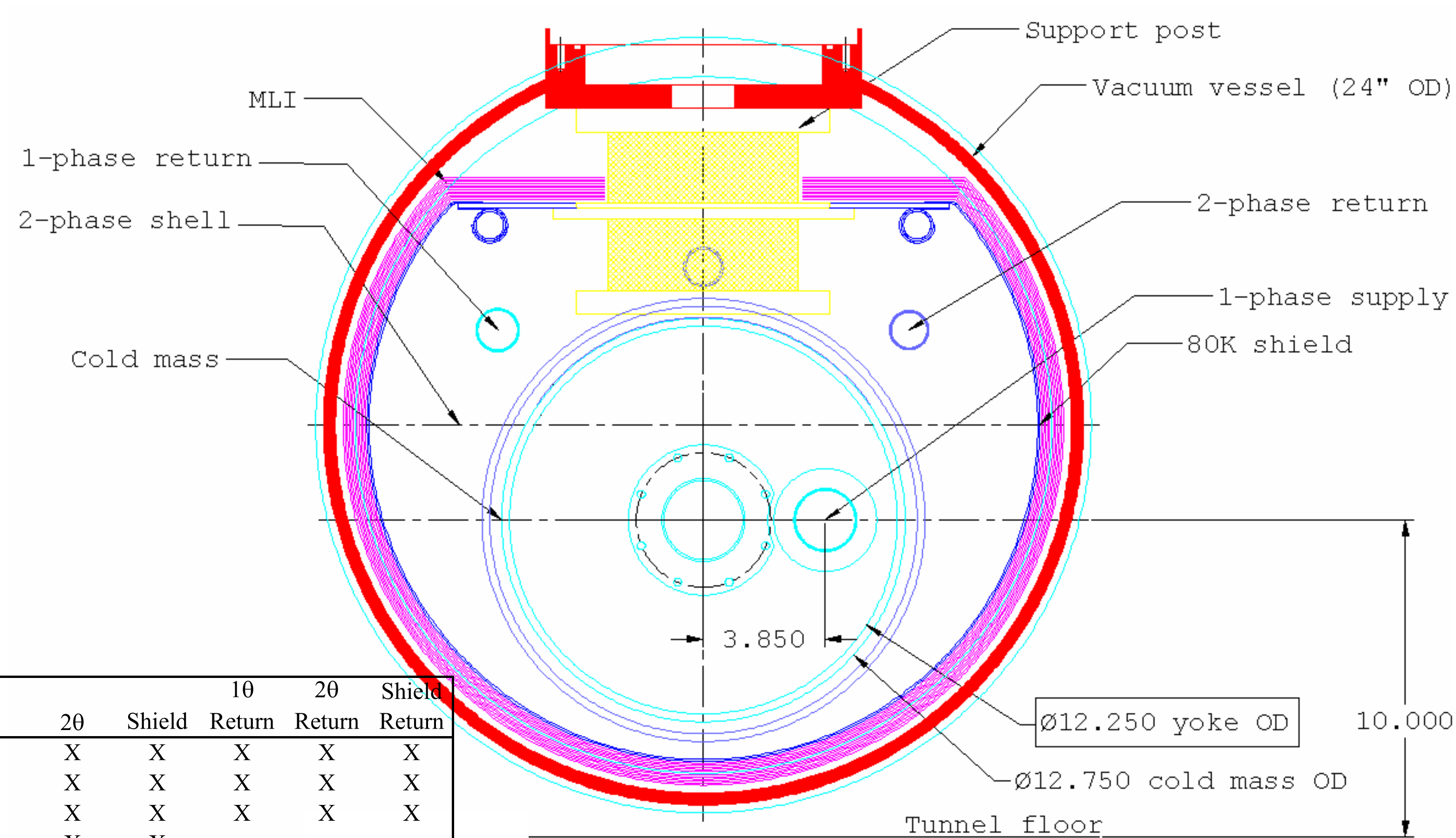






Q1-Q5 Quadrupoles

- Preliminary Cryostat Design (Q2)
  - Tev interfaces satisfied



Magnet	1θ	2θ	Shield	1θ Return	2θ Return	Shield Return
Q1	X	X	X	X	X	X
Q2	X	X	X	X	X	X
Q3	X	X	X	X	X	X
Q4	X	X	X			
Q5	X	X	X			

Spool Pieces

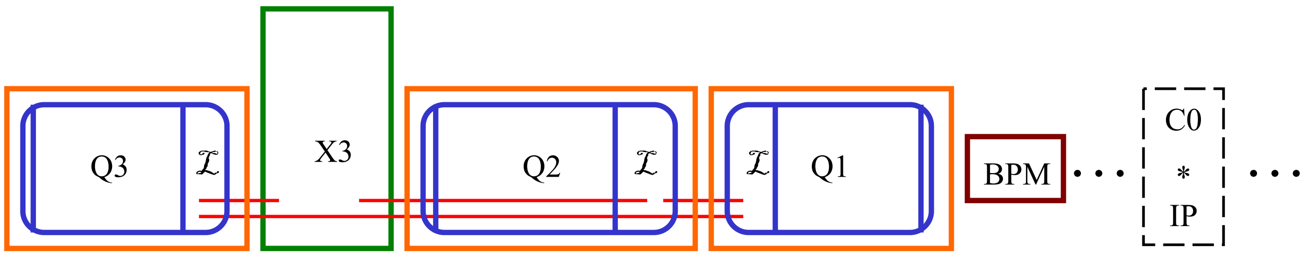
- For the (lucky) uninitiated, a definition:
  - A Tevatron spool piece is where you cram all the other stuff that doesn't fit on a normal arc magnet
- This usually includes some large fraction of this not all inclusive list:
  - Corrector magnets (of whatever variety)
  - Power leads, big and small, for magnets/correctors both near and far
  - Instrumentation leads
  - Beam position monitors
  - Relief valves
  - Cryogenic pipe interfaces as needed
  - Bus pass throughs as needed
  - Quench stoppers
  - …

Spool Pieces

- The C0 IR requires 3 spool designs, with potential left/right or magnetic element variations in 2 of the designs → 5 installed variants

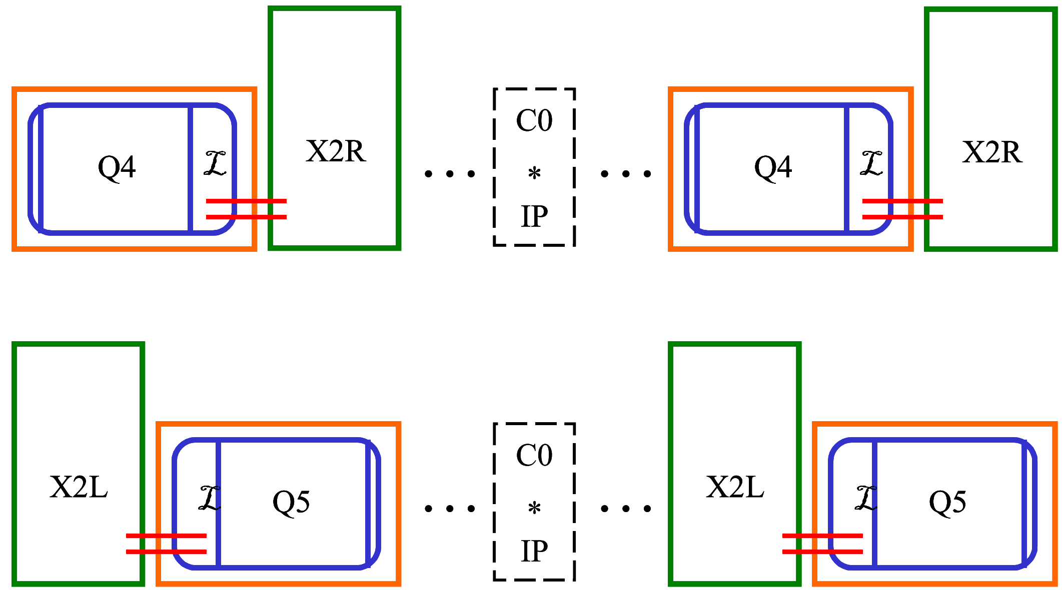
Spool	Location	Slot Length, m	VD T. m	HD T. m	SQ T.m/m	Sx T.m/m^2	Q* T.m/m	BPM	HTS Leads	Other Leads
X1V	packb43	1.83	0.48			450	25			3x50A+SL
X1H	packb44	1.83		0.48		450	25			3x50A
X2L	packb47	1.43	0.48	0.48				V&H	2x10kA	2x50A+SL
X2R	packb48	1.43	0.48	0.48				V&H	2x10kA	2 x50A
X3	packc0u	1.43	0.48	0.48	7.5			V&H	2x10kA	3x50A+200A
X3	packc0d	1.43	0.48	0.48	7.5			V&H	2x10kA	3x50A+200A
X2R	packc12	1.43	0.48	0.48				V&H	2x10kA	2x50A
X2L	packc13	1.43	0.48	0.48				V&H	2x10kA	2x50A+SL
X1V	packc16	1.83	0.48			450	25			3x50A
X1H	packc17	1.83		0.48		450	25			3 x 50A+ SL

Spool Pieces



Q1—Q2—X3—Q3
(mirror image about IP not shown for space)

- Spools are located between other components, either new quads or existing Tev equipment (not shown here)
  - X2 variations driven by Q4/Q5 optics
  - X1 variations driven by H/V Dipole corrector requirement



Spool Pieces

- BTeV spools require
  - New Correction Elements
  - HTS Leads
  - Newly engineered assemblies
    - Complete component list
    - Designed to FESHM 5031 / ASME BPV Standards
    - Understood interfaces to surrounding equipment

ocation	Designation	US comp.	US interface	US bus	DS comp.	DS interface	DS bus
ackb43	X1V	Quad	Tev	Tev	Dipole	Tev	Tev
ackb44	X1H	Quad	Tev	Tev	Dipole	Tev	Tev
ackb47	X2L	Q5	Modified Tev?	Tev, LHC	Dipole	Tev	Tev
ackb48	X2R	Cold bypass	Tev	Tev	Q4	Modified Tev?	Tev, LHC
ackc0u	X3	Q3	New	LHC	Q2	New	LHC
ackc0d	X3	Q2	New	LHC	Q3	New	LHC
ackc12	X2R	Dipole	Tev	Tev	Q4	Modified Tev?	Tev, LHC
ackc13	X2L	Q5	Modified Tev?	Tev, LHC	Dipole	Tev	Tev
ackc16	X1V	Quad	Tev	Tev	Dipole	Tev	Tev
ackc17	X1H	Quad	Tev	Tev	Dipole	Tev	Tev

Spool Pieces

Table 1: Corrector packages in each spool.

Spool Name	Corrector Package Mechanical Length m	Vertical Dipole T. m	Horizontal Dipole T. m	Skew Quadrupole T.m/m	Sextupole $T.m/m^2$	Normal Quadrupole T.m/m
X1V	1.200	0.48			450	25
X1H	1.200		0.48		450	25
X2L	0.550	0.48	0.48			
X2R	0.550	0.48	0.48			
X3	0.800	0.48	0.48	7.5		

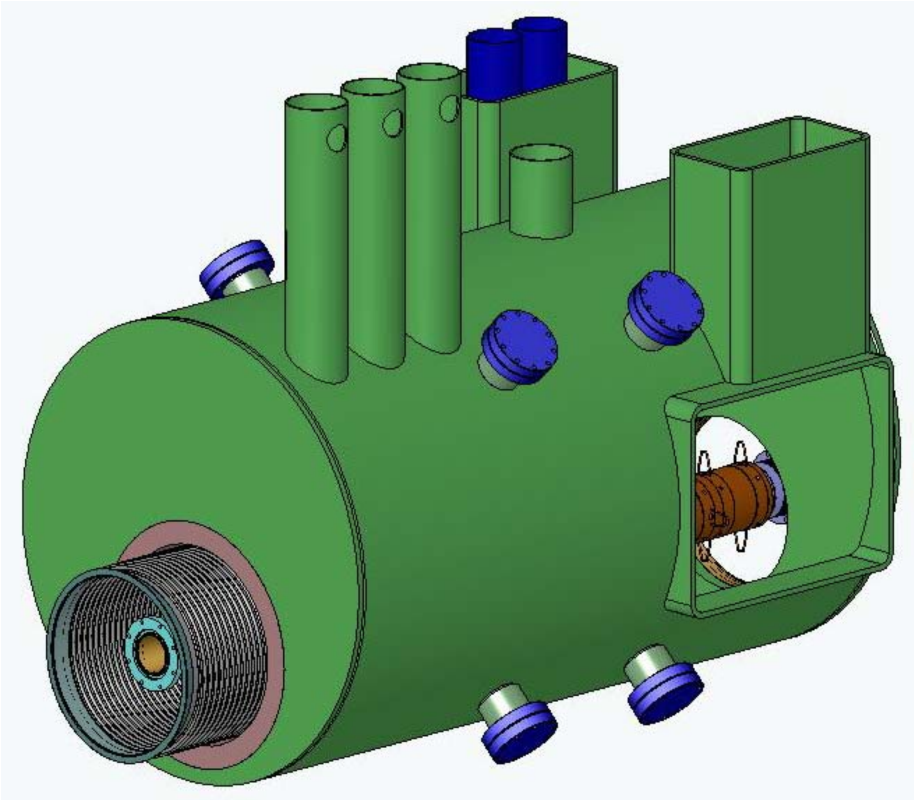
- Corrector magnet requirements
  - Stronger than existing (20 year old) Tevatron design
  - Packaging requirements vary
- C0 corrector design(s)
  - CDR includes a baseline design using current 'LHC-like' technology
  - We have solicited designs from 3 outside sources, 1 response so far, another 'next week'…appear technically viable

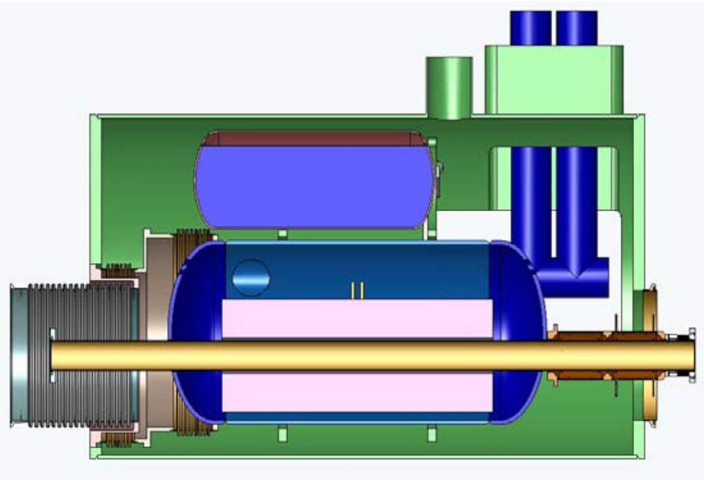
Spool Pieces

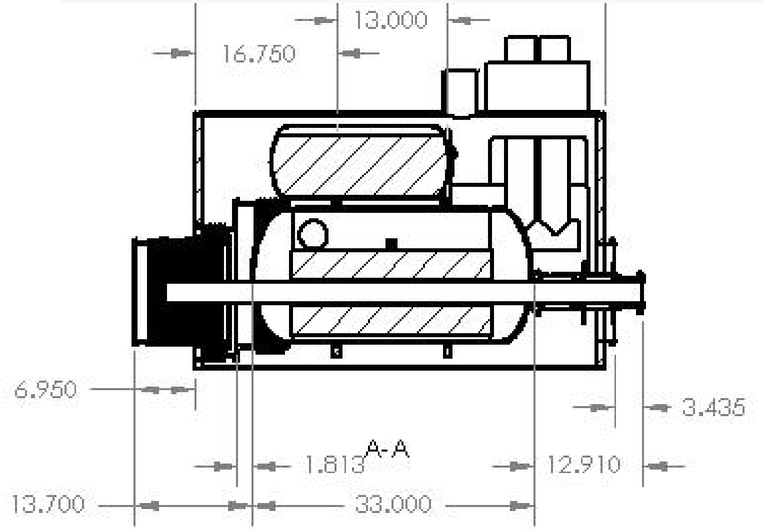
- HTS Leads
  - Currently used in TSHH spools in the Tevatron, but only up to 5kA
    - Tevatron cooling (LN2) an issue relative to other designs
  - Are not an off-the-shelf item; each is custom manufactured by vendor
  - Industry has contracted over past few years
- Investigating robustness of currently installed Tev design
  - Tests of TSHH spool to higher current successful!!
  - Need to identify willing vendor to duplicate lead—minimal design work needed if they so desire
  - Have started discussions w/ vendors

Spool Pieces

- Final Assembly…X2 Spool Preliminary Design

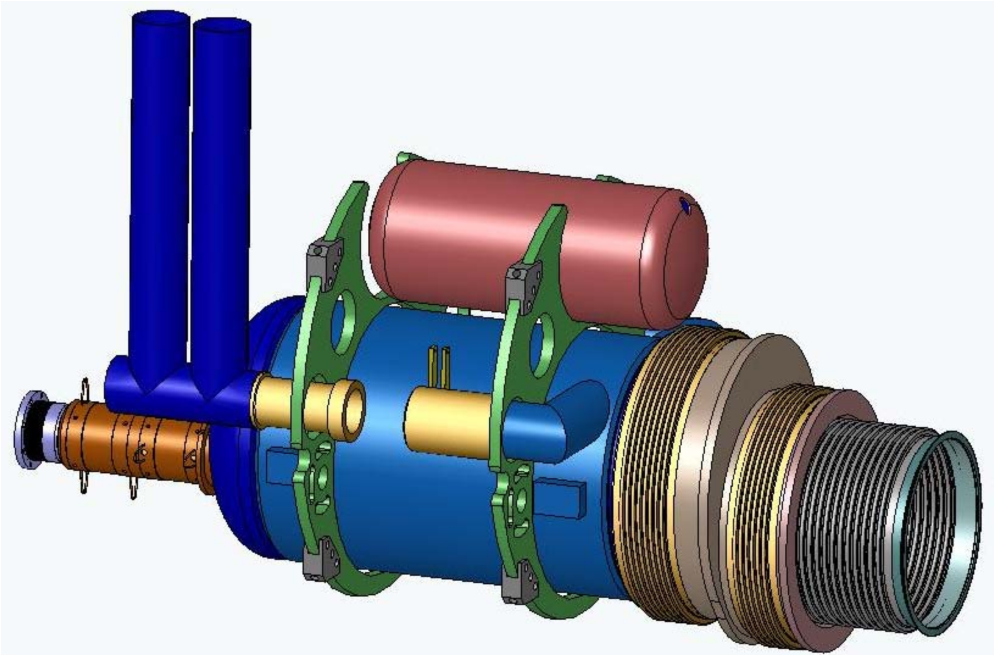






Spool Pieces

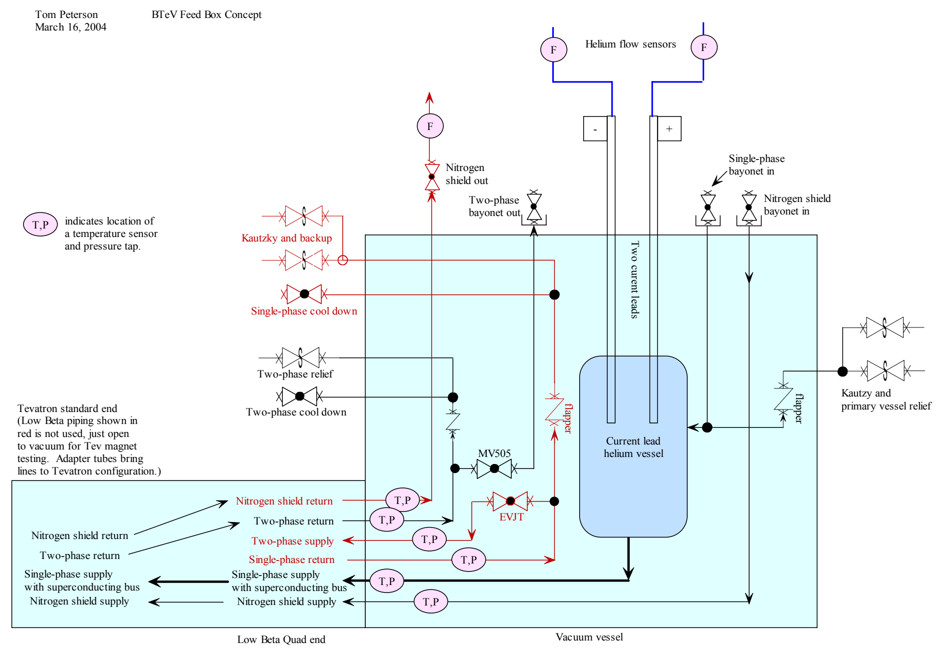
- Final Assembly…plan is to develop design internally, fabricate off-site, and final test here
  - Piping and final assembly similar to LHC DFBX style task, among others
  - HTS lead and correctors would come as tested items
  - Final spool design dependent on technical solution to these two major items, among others.



Innards of an X2 spool

Infrastructure

- ICB Production facility largely in place
  - Length changes in coil drive modest changes / variants of winding / curing / measuring / collaring tooling
- Test facility modifications similar in nature to ICB
  - Test stand largest item, but similar to previous designs
  - Measurement equipment very similar to LHC



Status / Cost / Schedule

- We are working on technical details, such as the HTS leads and the correctors.
- We have used the CDR to generate a cost estimate. It is in OpenPlan.
  - We are working to better define the basis of estimate, revise the estimate, and scrub it
  - The Quadrupoles have a relatively solid basis, from years of ongoing LHC production experience
  - The spool pieces, and subcomponents, are much more variable
    - We have included estimates based on recent similar experience, and are focusing our technical efforts to better define these items

Status / Cost / Schedule

- Our estimate (or range) has been reviewed twice in the past 6 months.
  - Minor changes through the reviews
- We have identified some early long lead item procurements, that have been invariant
  - NbTi cable for the quads
  - HTS leads
  - Corrector magnets
  - Collar steel (smaller in $$)
- We continue to work on technical details that drive the estimate
  - HTS leads and correctors, in particular…

Status / Cost / Schedule

- Our schedule is consistent with delivering tested components to BTeV in time for the summer 09 shutdown.
- Earlier details of the schedule will depend on our technical designs and our negotiations with suppliers.
- The cost and schedule is not at CD-2 status, yet.
  - But it will be
  - Active discussions w/ vendors
  - Active design work
  - Hiring of personnel to augment project staff
  - Rework of lower level WBS to add detail
    - Then adding backup to the details